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Research Article

The Effect of Unbalance Supply on the Three- Phase Synchronous Motor Performance in the Laboratory

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ABSTRACT

A detrimental worldwide phenomena that affects the output of three-phase synchronous motors is voltage unbalance. There are several ways that a three-phase source voltage can become unbalanced. A motor may be practically impacted by imbalanced instances that vary in several ranges. The goal of this work is to assess the operations using relevant hypotheses. To understand the degree of such modifications, this paper examines balanced and imbalanced situations practically in relation to their mechanical and electrical performance. This performance entails the currents of stator, total harmonics distortion, the speed of the motor, and the efficiency. The experiment was conduct laboratory on three phase synchronous motor.

Keywords: Unbalance Supply, Three- Phase Synchronous Motor

INTRODUCTION

For many years, the synchronous machine has held the foremost position among electromechanical power-conversion apparatuses, serving as a vital component in both electricity generation and specific specialty drive uses[1]. Three phase synchronous motors have been used for long time in industrial applications requiring constant speed operation in addition to power systems for improving the voltage profile of the power grid by absorbing the excessive reactive power available at selected locations[2]. Both motor and generator modes of operation are available for the synchronous machine. the three-phase synchronous motor's stator features a three-phase dispersed winding Similar to the three-phase induction motor. the stator winding which is linked to the ac supply system is occasionally referred to as the armature winding. It's made to withstand high current and voltage. Direct current is carried by a winding on the rotor known as the field winding. Typically, an external DC source is delivered by brushes and slip rings to the rotating structure's field winding[3].When the motor reaches synchronous speed, the damper winding won't experience any induced current, so it is removed from the operation of the motor. If the rotor speed deviates from the synchronous speed due to a fast change in load or other transients, the damper winding will induce currents to provide a torque that will bring the synchronous speed back[4]. A three-phase equipment is designed to operate under balanced three-phase supplies, while A three-phase supply can become unbalanced due to operational realities such as uneven line current switching, faulty transformer windings, imbalanced transformer windings, unequal single-phase loads on each of the three phases of the supply, etc. In addition to increasing operational losses, voltage imbalance can result in thermal transients in machines and harmonic currents in windings. So Electrical systems must have excellent power quality. Voltage imbalance in power and electrical systems can be solved using a variety of techniques, some of which are analytical and others of which are experimental[5], [6]. Over the past two years, a number of experts have published various research on synchronous motors.**D Aguilar, F Ferreira, A De Almeida, M Cistelecan ,2022**discussed beginning torque, part- and full-load efficiency, and synchronization. Furthermore, the mains voltage's magnitude deviation and/or imbalance, which significantly impair starting Line-start permanent magnet synchronous motors' (LSPMSM) torque and synchronous speed, with special focus on the motor's steady-state performance and the consequences of voltage imbalance and magnitude variation[7]. **AA Kebir, M Ayad, S Kamel,2022** explore how harmonic pollution and voltage imbalance affect the five-phase permanent magnet synchronous machine using spectrum current analysis and wavelet transform[8]. **Elsevier,**

2023 offers a methodical approach to determining the values of synchronous machine parameters and the associated circuit.The study expands to examine the performance characteristics of the machines and the behavior of three-phase synchronous machines under both dynamic and steady-state settings. The effect of load changes on the synchronous motor with a fixed field excitation is demonstrated by plotting the phasor diagram and the influence of varying field excitation in terms of V-curves. Furthermore, the connection between torque, excitation, and current is studied[9].

This work aims to investigate how a synchronous motor's performance in steady-state conditions is affected by supply voltage imbalance using a device Power and quality analyzer. Performance comparisons of the motor under two cases supply voltage unbalance factors on the Stater current, Real input power, reactive power, power factor, efficiency and speed. It is anticipated that an uneven and distorted voltage source will affect the motor in a number of ways.

SYNCHRONOUS MACHINE MODELING

This study uses the Park transformation for modeling the synchronous machine with a single d-axis damper winding. The equations for the models originate from the d-q circuit shown in **Error! Reference source not found.** [10]

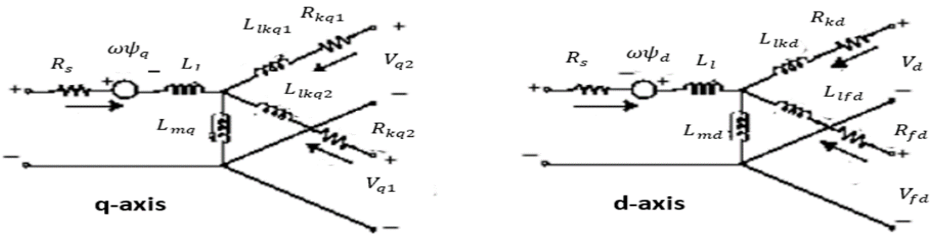


Figure 1 The dynamic model of synchronous machines with direct and quadratic axes

$$V_d = -i_d R_s - \omega\psi_d + \frac{d\omega_d}{dt} \quad (1)$$

$$V_q = -i_q R_s + \omega\psi_q + \frac{d\omega_q}{dt} \quad (2)$$

$$V_0 = -i_0 R_0 + \frac{d\omega_0}{dt} \quad (3)$$

$$V_{fd} = \frac{d\omega_{fd}}{dt} + i_{fd} R_{fd} \quad (4)$$

$$0 = \frac{d\omega_{kd}}{dt} + i_{kd} R_{kd} \quad (5)$$

$$0 = \frac{d\omega_{kq1}}{dt} + i_{kq1} R_{kq1} \quad (6)$$

$$0 = \frac{d\omega_{kq2}}{dt} + i_{kq2} R_{kq2} \quad (7)$$

the relationship between current and flux can be expressed as:

$$\begin{bmatrix} \psi_d \\ \psi_{kd} \\ \psi_{fd} \end{bmatrix} = \begin{bmatrix} L_l + L_{md} & L_{md} & L_{md} \\ L_{md} & L_{lkd} + L_{fld} + L_{md} & L_{fld} + L_{md} \\ L_{md} & L_{fld} + L_{md} & L_{lfd} + L_{lfd} + L_{md} \end{bmatrix} \begin{bmatrix} -i_d \\ i_{kd} \\ i_{fd} \end{bmatrix} \quad (8)$$

$$\begin{bmatrix} \psi_q \\ \psi_{kq1} \\ \psi_{kq2} \end{bmatrix} = \begin{bmatrix} L_{mq} + L_l & L_{mq} & L_{mq} \\ L_{mq} & L_{mq} + L_{kq1} & L_{mq} \\ L_{mq} & L_{mq} & L_{mq} + L_{kq2} \end{bmatrix} \begin{bmatrix} -i_q \\ i_{kq1} \\ i_{kq2} \end{bmatrix} \quad (9)$$

The system's electromagnetic torque in a full dynamic model is

$$T_e = \psi i_{ds} * i_q - \psi i_{qs} * i_d \quad (10)$$

Where:

d, q are the quantity on the d- and q-axis, s is the quantity of stator, l, m are the inductance of leakage and magnetization, f, k are the quantity of field and damper windings

STEADY STATE ANALYSIS OF THREE PHASE SYNCHRONOUS MOTORS

Since The synchronous machine's rotor does not provide a balanced impedance to the machine's stator, in contrast to the induction machine, which can easily handle such imbalances analytically, so this leads to a solution that is far more complex. there is basic method for analyzing such issues, where it is assumed that each machine phase is made up of an arbitrary number of harmonics. When considering the broader that when the three source voltages are arbitrary periodic functions, it is helpful to examine the case of a three-wire, three-phase synchronous machine operating in steady-state. It is assumed that the three source voltages have the same fundamental frequency component and are periodic for the sake of simplicity. If this were untrue, it is still possible to solve the currents by superposition, which involves adding the solutions for each basic component.

For Figure 1, If the three source voltages are periodic, they can be expressed generally as

$$e_{am} = \sum_{k=0}^{\infty} E_{ka\alpha} \cos \theta_e t + \sum_{k=0}^{\infty} E_{ka\beta} \sin \theta_e t \qquad 11$$

$$e_{bm} = \sum_{k=0}^{\infty} E_{kb\alpha} \cos \theta_e t + \sum_{k=0}^{\infty} E_{kb\beta} \sin \theta_e t \qquad 12$$

$$e_{cm} = \sum_{k=0}^{\infty} E_{kc\alpha} t \cos \theta_e t + \sum_{k=0}^{\infty} E_{kc\beta} \sin \theta_e t \qquad 13$$

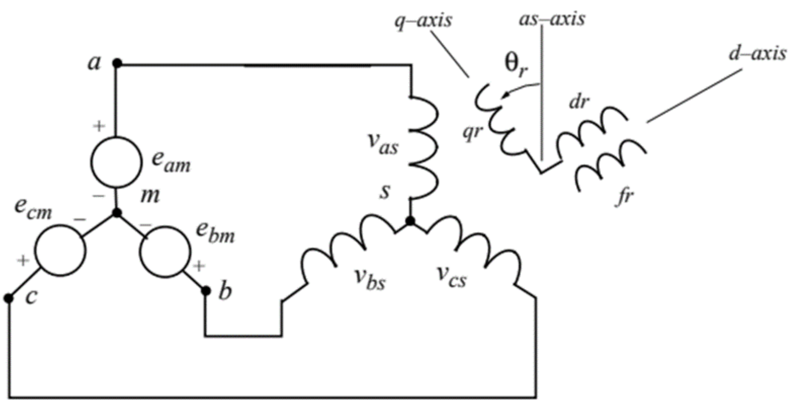


Figure 2 Synchronous machine with Source voltages with random periodicity

wherein it is acknowledged that $E_{0a\alpha}, E_{0b\alpha}, E_{0c\alpha}$ are the three source voltages' DC components and $E_{0a\beta} = E_{0b\beta} = E_{0c\beta} = 0$

In the stationary reference frame, the d-q voltages are

$$v_{ds}^{s} = \sum_{k=0}^{\infty} V_{kd\alpha} \cos \theta_e t + \sum_{k=0}^{\infty} V_{kd\beta} \sin \theta_e t \qquad 14$$

$$v_{qs}^{s} = \sum_{k=0}^{\infty} V_{kq\alpha} \cos \theta_e t + \sum_{k=0}^{\infty} V_{kq\beta} \sin \theta_e t \qquad 15$$

whereby the relationship between the source voltage harmonics and the harmonics of the v_{ds}^{s}, v_{qs}^{s} variables is

$$V_{kd\alpha} = \frac{1}{\sqrt{3}}(E_{kc\alpha} - E_{kb\alpha}) \qquad 16$$

$$V_{kq\beta} = \frac{1}{\sqrt{3}}(E_{kc\beta} - E_{kb\beta}) \qquad 17$$

$$V_{kq\alpha} = \frac{2}{3}E_{ka\alpha} - \frac{1}{3}E_{kb\alpha} - \frac{1}{3}E_{kc\alpha} \quad 18$$

$$V_{kq\beta} = \frac{2}{3}E_{ka\beta} - \frac{1}{3}E_{kb\beta} - \frac{1}{3}E_{kc\beta} \quad 19$$

It is not practicable to transform each stator voltage to a synchronously rotating frame and since the inductances of a synchronous machine become time invariant only when represented in the rotor reference frame. Therefore, so it is transformed the d−q voltages to a reference frame rotating at rotor speed[11]. The transformational equations are

$$v_{ds}^{r} = v_{qs}^{s}\sin\theta_r t + v_{ds}^{s}\cos\theta_r t \quad 20$$

$$v_{qs}^{r} = v_{qs}^{s}\cos\theta_r t - v_{ds}^{s}\sin\theta_r t \quad 21$$

Substituting Eqs.14,15 into Eqs. 20 and 21 One gets

$$v_{ds}^{r} = \sum_{k=0}^{\infty}\left[V_{kq\alpha}\cos\theta_e t\sin\theta_r t + V_{kq\beta}\sin\theta_e t\sin\theta_r t + V_{kd\alpha}\cos\theta_e t\cos\theta_r t + V_{kd\beta}\sin\theta_e t\cos\theta_r t\right] \quad 22$$

$$v_{qs}^{r} = \sum_{k=0}^{\infty}\left[V_{kq\alpha}\cos\theta_e t\cos\theta_r t + V_{kq\beta}\sin\theta_e t\cos\theta_r t - V_{kd\alpha}\cos\theta_e t\sin\theta_r t - V_{kd\beta}\sin\theta_e t\sin\theta_r t\right] \quad 23$$

$$v_{ds}^{r} = \sum_{k=0}^{\infty}\left[\frac{1}{2}\left(V_{kq\alpha} + V_{kd\beta}\right)\sin(k\theta_e + \theta_r)t - \frac{1}{2}\left(V_{kq\beta} - V_{kd\alpha}\right)\cos(k\theta_e + \theta_r)t - \frac{1}{2}\left(V_{kq\alpha} - V_{kd\beta}\right)\sin(k\theta_e - \theta_r)t + \frac{1}{2}(V_{kq\beta} + V_{kd\alpha})\cos(k\theta_e - \theta_r)t\right] \quad 24$$

$$v_{qs}^{r} = \sum_{k=0}^{\infty}\left[\frac{1}{2}\left(V_{kq\alpha} + V_{kd\beta}\right)\cos(k\theta_e + \theta_r)t + \frac{1}{2}\left(V_{kq\beta} - V_{kd\alpha}\right)\sin(k\theta_e + \theta_r)t + \frac{1}{2}\left(V_{kq\alpha} - V_{kd\beta}\right)\cos(k\theta_e - \theta_r)t + \frac{1}{2}(V_{kq\beta} + V_{kd\alpha})\sin(k\theta_e - \theta_r)t\right] \quad 25$$

Where:

θ_e is the machine's electrical angle. θ_r is the machine's angular velocity

Total Harmonic Distortion (THD)

One of the most significant measurement indices utilized assess power system quality in a methodical and comparable manner is total harmonic distortion (THD), which contributes to higher power system quality and lower distortion levels. THD is a measure of the percentage of signal energy difference from the fundamental component, which is typically the main component in power systems, particularly when it comes to voltage. It should be noted that, although there are other power quality indices such as power factor, individual harmonic measurement, and so on to quantify waveform distortion, and European standards for renewable energy systems, like grid-connected photovoltaic systems, only address the THD distortion factor when determining the amount of harmonic pollution. Furthermore, a large number of the commercial quality testing devices available today only measure the THD factor; they do not account for total interharmonic distortion or measure in high frequency ranges. Thus, it is convenient to examine which distortion factor among the ones that are already described is best suited for identifying harmonic in power systems[12].

Total harmonic distortion can be expressed as a percentage. It is the difference between the root mean square (RMS) values of the harmonic and fundamental components. In an entirely sinusoidal waveform, the THD value is zero[13]. The following can be used to express the total harmonic distortion of the voltage and current waveforms, respectively:

$$THD_I = \frac{\sqrt[2]{\sum_{h=0}^{\infty} I_h}}{I_1} \quad 26$$

$$THD_V = \frac{\sqrt[2]{\sum_{h=0}^{\infty} V_h}}{V_1} \quad 27$$

Equilibrium Sinusoidal Supply Results

A synchronous motor shown in Figure 3 with specifications shown in the Table 1 was chosen for the purpose of studying the effect of balanced and unbalanced voltages with 87.8w load.

Figure 3 The synchronous motor

Specifications	Value	Specifications	Value
Rated power	350 KW	Poles	2
Rated voltage	400/240 V	stator current	0.7 A
Speed	3000 rpm	Frequency	50 HZ
Excitation voltage	220 v	Connection	Y
Excitation current	0.45 A		

Table 1 Parameters of synchronous motor

with the purpose of creating a benchmark for comparison testing was done under normal operating conditions, with 87.8w load in case unite and lead power factor, this setup is shown in Figure 4

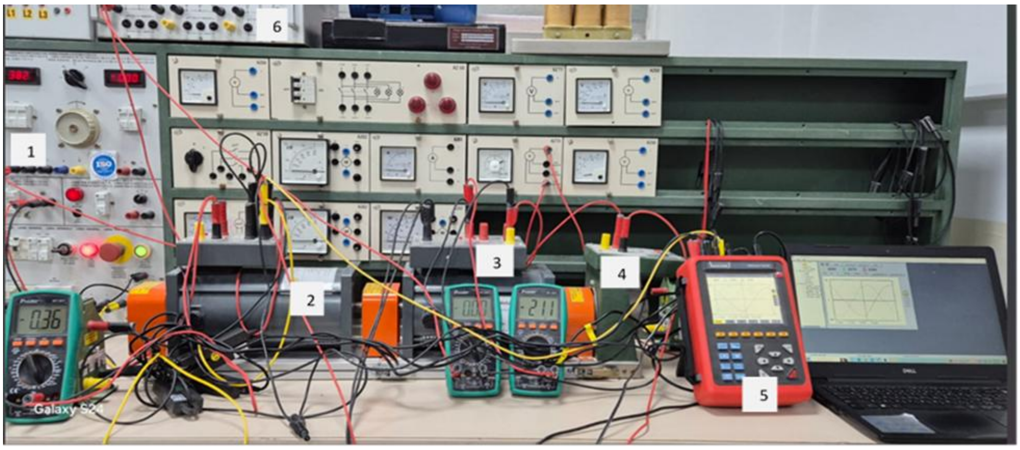


Figure 4 The Setup to Show the Effect of Unbalance Voltage on The Performance of Synchronous Motor

The components of the setup are as follows:

1-Power supply for DC and AC three phase voltage

2-Three phase synchronous machine (mod.M-3/EV)

3-DC motor/generator (mod .M1-2/EV)

4-Tachogenerator (mod.M-16/EV)

5-Power and quality analyzer (HZCR-5000)

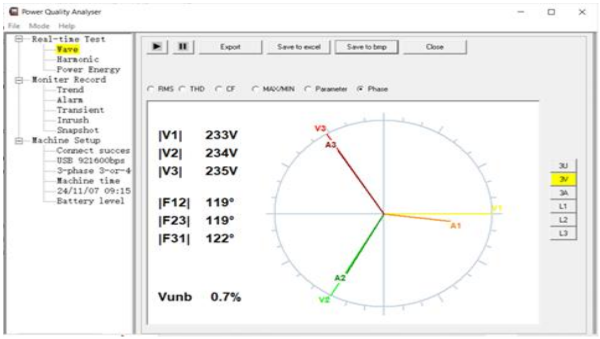
6-Variable load (mod.RL-1/EV)

Readings were made, When the motor was operating normally, it received a rated voltage of 400 volts (line to line). Following are the voltages that were applied:

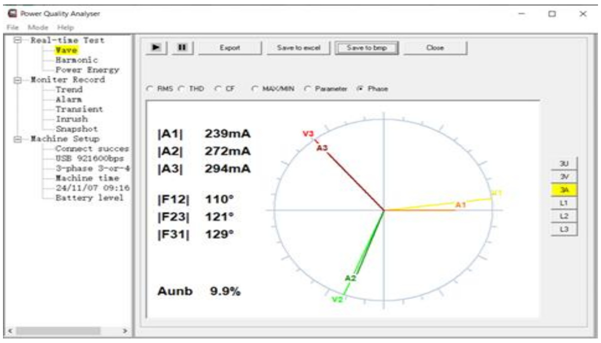
$$V_a = 230\angle 0 \qquad V_b = 230\angle - 120 \qquad V_c = 230\angle 120$$

Machine setup information					
Machine ti	24/11/7 9:14:5				
Reacitve v	Without harmonic				
Electrial cc	3-phase 4-wire				
	L1	L2	L3	?	avg
W	50.63	64.01	70.99	185.6	
VAR	inductive6	Capacitive	Capacitive	inductive4.411	
VA	52.19	64.57	72	188.8	
Consume energy					
Wh	0	0	0	0	
VARh	Inductive0	Inductive0	Inductive0	Inductive0.000	
	Capacitive	Capacitive	Capacitive	Capacitive0.000	
VAh	0	0	0	0	
Generate energy					
Wh	0	0	0	0	
VARh	Inductive0	Inductive0	Inductive0	Inductive0.000	
	Capacitive	Capacitive	Capacitive	Capacitive0.000	
VAh	0	0	0	0	
PF	0.97	0.991	0.986		0.982
cosf	0.992	1	0.999		0.997
tanf	0.123	-0.003	-0.022		0.032
fVA	7	-0.2	-1.3		
Energy calculate start time:					
########					
Energy calculate stop time:					
########					

Table 2 Input Power and Power Factor at Balance Conditions for Unity p.f

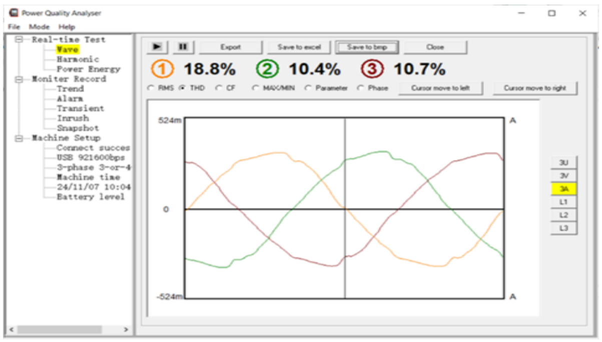


(a) Three phase voltage magnitude and phases



(b) Three phase current magnitude and phases

(c) Three phase voltage THD



(d) Three phase current THD

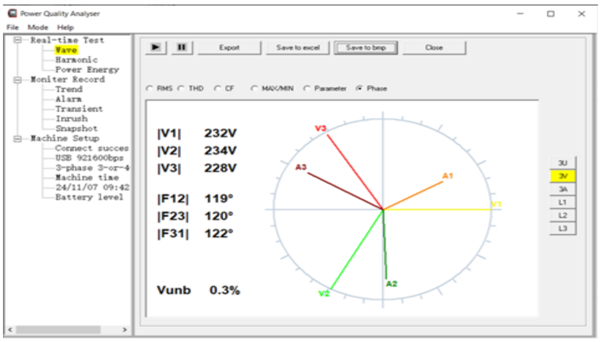
$I_{exc}(A)$	$I_L(A)$	$V_L(v)$	$P_{out}(w)$	$T(N*m)$	$Eff.$	Speed(rpm)
0.29	0.32	247	87.8	0.2794	0.473	3000

(e) Result for unity p.f

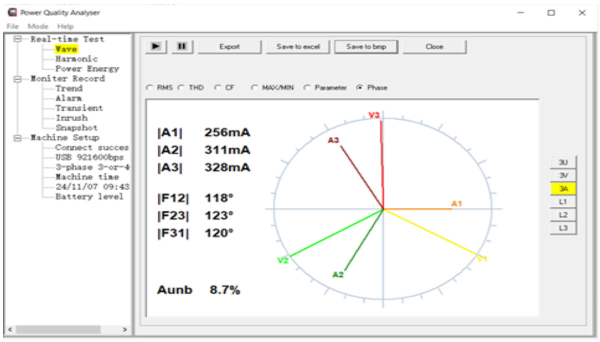
Figure 5 Performance of Synchronous Motor at Balance Conditions Unity p.f

Machine setup information					
Machine ti 24/11/7 9:37:12					
Reacitve v Without harmonic					
Electrial cc 3-phase 4-wire					
	L1	L2	L3	?	avg
W	52.32	61.56	61.68	175.6	
VAR	Capacitive	Capacitive	Capacitive	Capacitive-106.1	
VA	61.61	74.3	72.8	208.7	
Consume energy					
Wh	0	0	0	0	
VARh	Inductive0	Inductive0	Inductive0	Inductive0.000	
	Capacitive	Capacitive	Capacitive	Capacitive0.000	
VAh	0	0	0	0	
Generate energy					
Wh	0	0	0	0	
VARh	Inductive0	Inductive0	Inductive0	Inductive0.000	
	Capacitive	Capacitive	Capacitive	Capacitive0.000	
VAh	0	0	0	0	
PF	0.849	0.828	0.847		0.841
cosf	0.87	0.836	0.867		0.857
tanf	-0.57	-0.657	-0.579		-0.602
fVA	-29.5	-33.2	-29.8		
Energy calculate start time:					
#########					
Energy calculate stop time:					
#########					

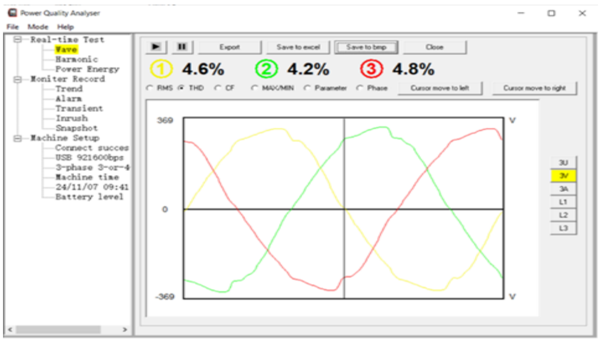
Table 3 Input power and power factor at Balance Conditions for leading p.f



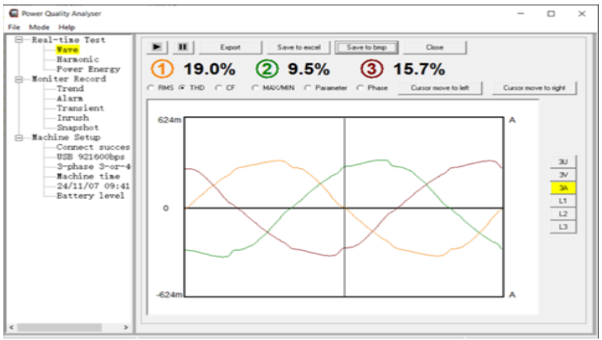
(a) Three phase voltage magnitude and phases



(b) Three phase current magnitude and phases



(c) Three phase voltage THD



(d) Three phase current THD

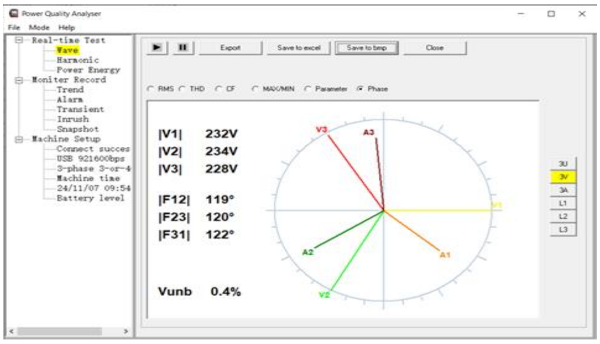
I_{exc}(A)	I_L(A)	V_L(v)	P_{out}(w)	T(N * m)	Eff.	Speed(rpm)
0.37	0.32	247	87.8	0.279	0.5	3000

(e) Result for Leading p.f

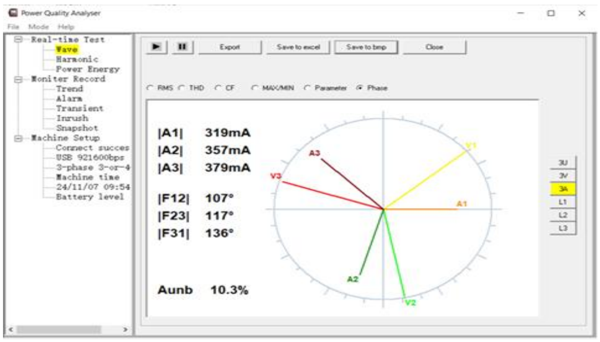
Figure 6 Performance of Synchronous Motor at Balance Conditions for Leading p.f

Machine setup information					
Machine ti 24/11/7 9:52:54					
Reacitve v Without harmonic					
Electrial cc 3-phase 4-wire					
	L1	L2	L3	?	avg
W	55.45	73.71	75.19	204.3	
VAR	inductive4	inductive3	inductive3	inductive124.6	
VA	74.66	84.38	84.89	243.9	
Consume energy					
Wh	0	0	0	0	
VARh	Inductive0	Inductive0	Inductive0	Inductive0.000	
	Capacitive	Capacitive	Capacitive	Capacitive0.000	
VAh	0	0	0	0	
Generate energy					
Wh	0	0	0	0	
VARh	Inductive0	Inductive0	Inductive0	Inductive0.000	
	Capacitive	Capacitive	Capacitive	Capacitive0.000	
VAh	0	0	0	0	
PF	0.742	0.873	0.885		0.833
cosf	0.755	0.885	0.894		0.844
tanf	0.866	0.527	0.5		0.631
fVA	40.9	27.7	26.6		
Energy calculate start time:					
########					
Energy calculate stop time:					
########					

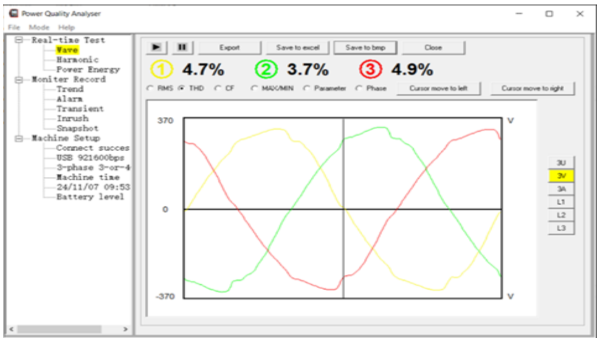
Table 4 Input power and power factor at Balance Conditions for Lagging p.f



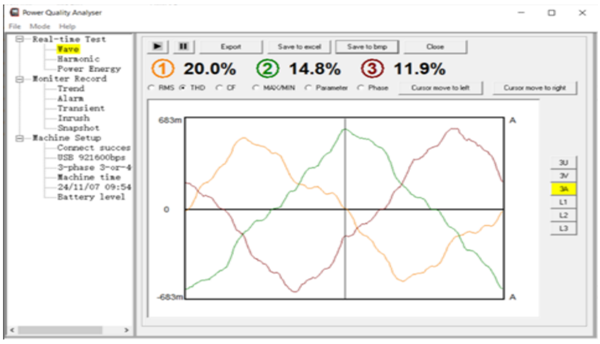
(a) Three phase voltage magnitude and phases



(b) Three phase current magnitude and phases



(c) Three phase voltage THD



(d) Three phase current THD

I_{exc}(A)	I_L(A)	V_L(v)	P_{out}(w)	T(N * m)	Eff.	Speed(rpm)
0.2	0.35	247	87.8	0.2794	0.429	3000

(e) Result for Lagging p.f

Figure 7 Performance of Synchronous Motor at Balance Conditions for Lagging p.f

Equilibrium of Unbalance Sinusoidal Supply Results

This section examines the performance of a three-phase synchronous motor by applying unbalance fluctuations in the voltage's phase and magnitude in two different scenarios:

a) Under Voltage in Magnitude

This testing was done under unbalance voltage with a load in case lead, lag and unite power factor. Following are the voltages that were applied:

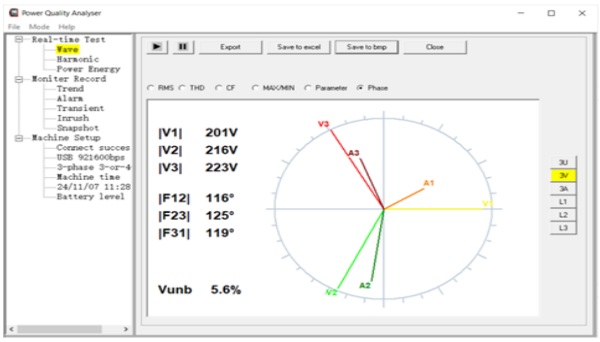
$$V_a = 202\angle 0 \qquad V_b = 217\angle -116 \qquad V_C = 223\angle 119$$

Machine setup information
Machine ti 24/11/7 11:26:36
Reacitve v Without harmonic
Electrial cc 3-phase 4-wire

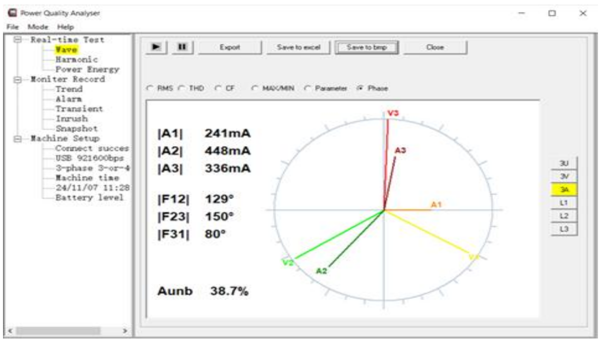
	L1	L2	L3	?	avg
W	37.91	88.56	67.6	194.1	
VAR	Capacitive	Capacitive	inductive	Capacitive	-41.69
VA	48.82	97.02	74.54	220.4	
Consume energy					
Wh	0	0	0	0	
VARh	Inductive0	Inductive0	Inductive0	Inductive0.000	
	Capacitive	Capacitive	Capacitive	Capacitive0.000	
VAh	0	0	0	0	
Generate energy					
Wh	0	0	0	0	
VARh	Inductive0	Inductive0	Inductive0	Inductive0.000	
	Capacitive	Capacitive	Capacitive	Capacitive0.000	
VAh	0	0	0	0	
PF	0.776	0.912	0.906		0.864
cosf	0.848	0.952	0.99		0.93
tanf	-0.604	-0.321	0.143		-0.26
fVA	-31.9	-17.7	8		

Energy calculate start time:
#########
Energy calculate stop time:
#########

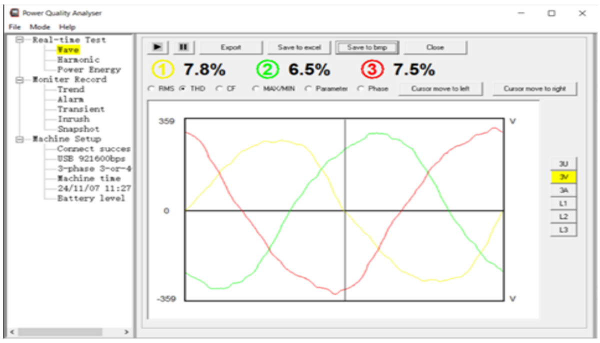
Table 5 Input power and power factor Unbalance Conditions (Under) for unity p.f



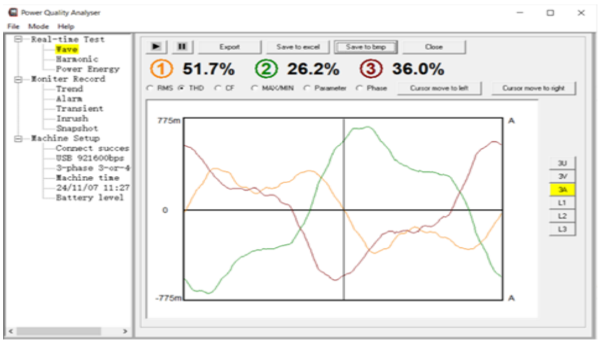
(a) Three phase voltage magnitude and phases



(b) Three phase current magnitude and phases



(c) Three phase voltage THD



(d) Three phase current THD

$I_{exc}(A)$	$I_L(A)$	$V_L(V)$	$P_{out}(w)$	$T(N.m)$	$Eff.$	Speed(rpm)
0.29	0.32	247	87.8	0.2762	0.447	3000

(e) Result for load unity p.f

Figure 8 Performance of Synchronous Motor at Unbalance Conditions (Under) for unity p.f

Machine setup information
Machine ti 24/11/7 11:38:22
Reacitve v Without harmonic
Electrial cc 3-phase 4-wire

	L1	L2	L3	?	avg
W	36.69	86.65	61.24	184.6	
VAR	Capacitive	Capacitive	Capacitive	Capacitive-142.7	
VA	70.62	111.3	72.03	253.9	

Consume energy

Wh	0	0	0	0
VARh	Inductive0	Inductive0	Inductive0	Inductive0.000
	Capacitive	Capacitive	Capacitive	Capacitive0.000
VAh	0	0	0	0

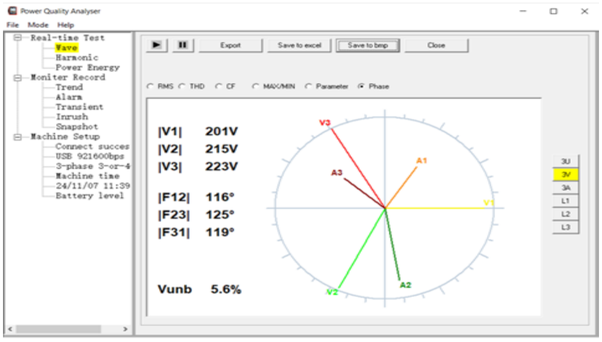
Generate energy

Wh	0	0	0	0
VARh	Inductive0	Inductive0	Inductive0	Inductive0.000
	Capacitive	Capacitive	Capacitive	Capacitive0.000
VAh	0	0	0	0

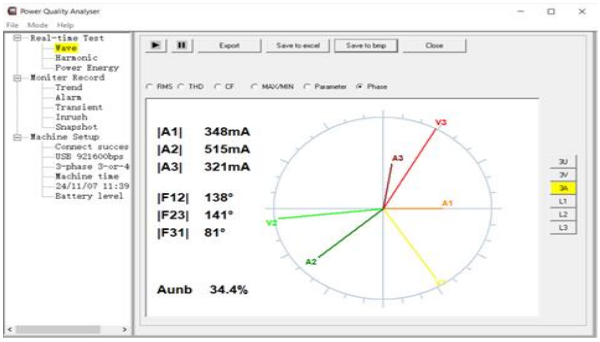
	L1	L2	L3	avg
PF	0.519	0.778	0.85	0.715
cosf	0.532	0.811	0.938	0.76
tanf	-1.533	-0.729	-0.378	-0.88
fVA	-57.8	-35.8	-20.2	

Energy calculate start time:
#########
Energy calculate stop time:
#########

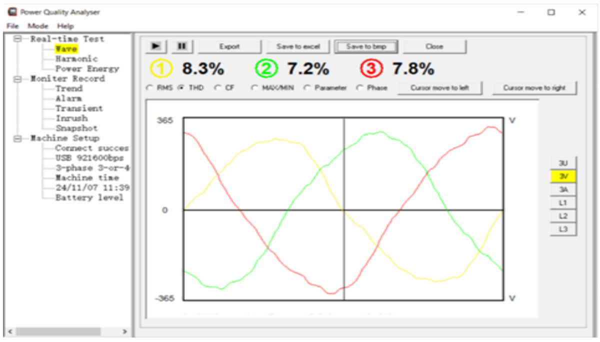
Table 6 Input power and power factor Unbalance Conditions (Under) for leading p.f



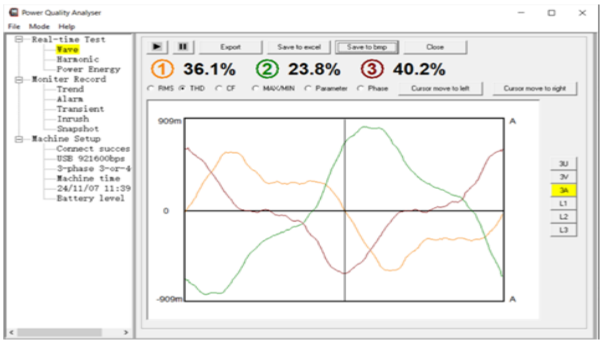
(a) Three phase voltage magnitude and phases



(b) Three phase current magnitude and phases



(c) Three phase voltage THD



(d) Three phase current THD

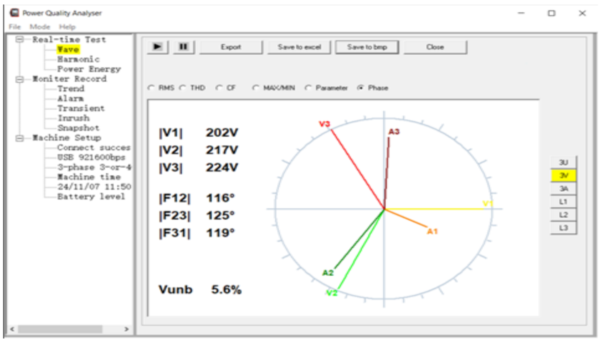
$I_{exc}(A)$	$I_L(A)$	$V_L(V)$	$P_{out}(w)$	$T(N.m)$	$Eff.$	Speed(rpm)
0.37	0.32	247	87.8	0.2762	0.475	3000

(e) Result Leading p.f

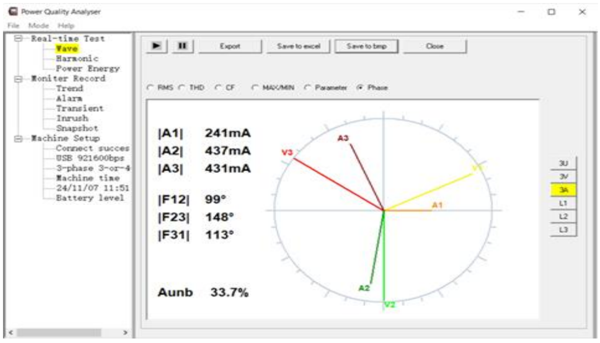
Figure 9 Performance of Synchronous Motor at Unbalance Conditions (Under) for Leading p.f

Machine setup information					
Machine ti 24/11/7 11:53:20					
Reacitve v Without harmonic					
Electrial cc 3-phase 4-wire					
	L1	L2	L3	?	avg
W	40.25	90.36	77.59	208.2	
VAR	inductive1	inductive1	inductive4	inductive83.75	
VA	48.47	94.66	96.32	239.4	
Consume energy					
Wh	0	0	0	0	
VARh	Inductive0	Inductive0	Inductive0	Inductive0.000	
	Capacitive	Capacitive	Capacitive	Capacitive0.000	
VAh	0	0	0	0	
Generate energy					
Wh	0	0	0	0	
VARh	Inductive0	Inductive0	Inductive0	Inductive0.000	
	Capacitive	Capacitive	Capacitive	Capacitive0.000	
VAh	0	0	0	0	
PF	0.83	0.954	0.805		0.863
cosf	0.895	0.987	0.847		0.909
tanf	0.487	0.159	0.641		0.429
fVA	26.4	9	32.1		
Energy calculate start time:					
#########					
Energy calculate stop time:					
#########					

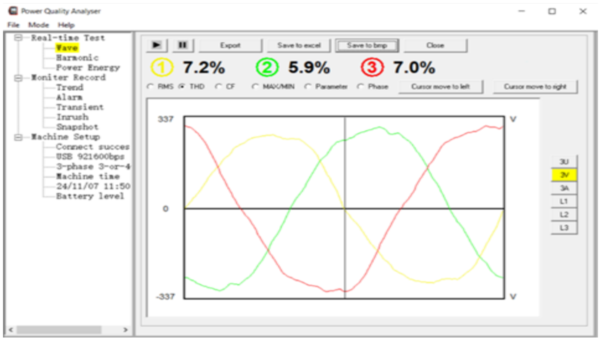
Table 7 Input power and power factor Unbalance Conditions (Under) for lagging p.f



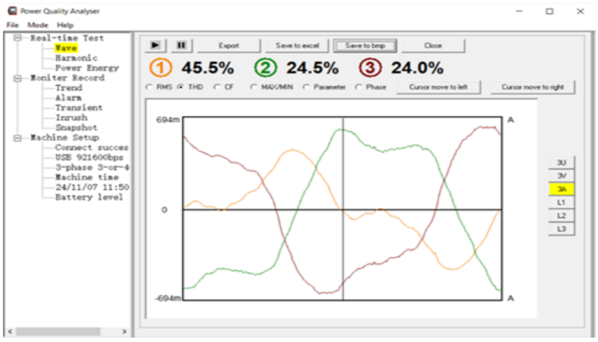
(a) Three phase voltage magnitude and phases



(b) Three phase current magnitude and phases



(c) Three phase voltage THD



(d) Three phase current THD

$I_{exc}(A)$	$I_L(A)$	$V_L(V)$	$P_{out}(w)$	$T(N.m)$	$Eff.$	Speed(rpm)
0.2	0.32	247	87.8	0.2762	0.421	3000

(E) Result for Lagging p.f

Figure 10 Performance of Synchronous Motor at Unbalance Conditions (Under) for Lagging p.f

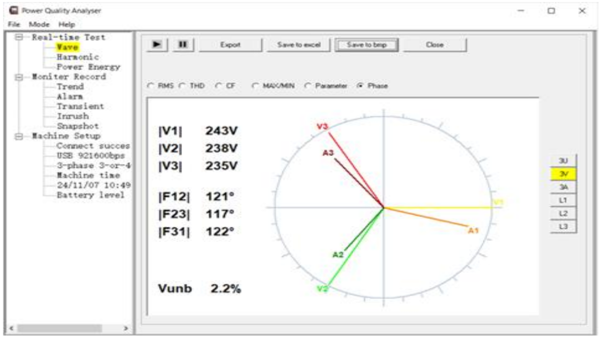
b) Over Voltage in Magnitude

This testing was done under unbalance voltage with load in case lead, lag and unite power factor. Following are the voltages that were applied:

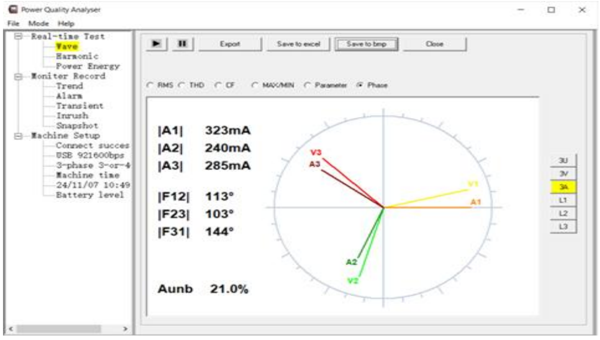
$$V_a = 245\angle 0 \qquad V_b = 239\angle -121 \qquad V_c = 236\angle 122$$

Machine setup information					
Machine ti 24/11/7 10:47:50					
Reacitve v Without harmonic					
Electrial cc 3-phase 4-wire					
	L1	L2	L3	?	avg
W	74.67	55.03	65.29	195	
VAR	inductive1	inductive€	Capacitive	inductive16.30	
VA	78.7	56.74	66.71	202.1	
Consume energy					
Wh	0	0	0	0	
VARh	Inductive0	Inductive0	Inductive0	Inductive0.000	
	Capacitive	Capacitive	Capacitive	Capacitive0.000	
VAh	0	0	0	0	
Generate energy					
Wh	0	0	0	0	
VARh	Inductive0	Inductive0	Inductive0	Inductive0.000	
	Capacitive	Capacitive	Capacitive	Capacitive0.000	
VAh	0	0	0	0	
PF	0.948	0.969	0.978		0.965
cosf	0.968	0.993	0.989		0.983
tanf	0.26	0.118	-0.147		0.077
fVA	14.4	6.7	-8.4		
Energy calculate start time:					
########					
Energy calculate stop time:					
########					

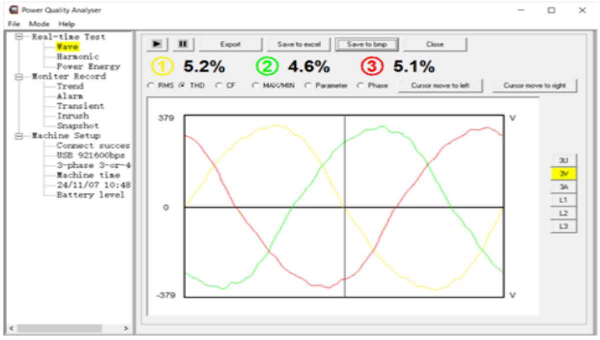
Table 8 Input Power and power Factor at Unbalance Condition (over) for Unity p.f



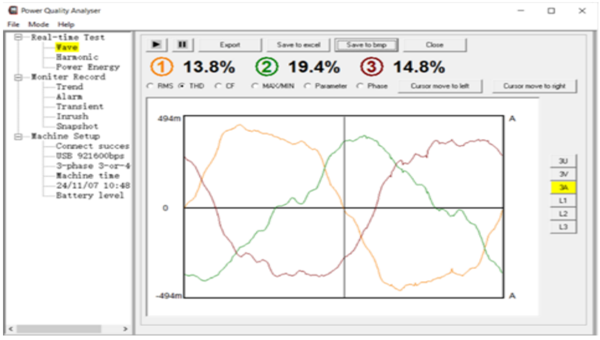
(a) Three phase voltage magnitude and phases



(b) Three phase current magnitude and phases



(c) Three phase voltage THD



(d) Three phase current THD

$I_{exc}(A)$	$I_L(A)$	$V_L(V)$	$P_{out}(w)$	$T(N.m)$	$Eff.$	Speed(rpm)
0.29	0.32	247	87.8	0.2794	0.447	3000

(E) Result for Unity p.f

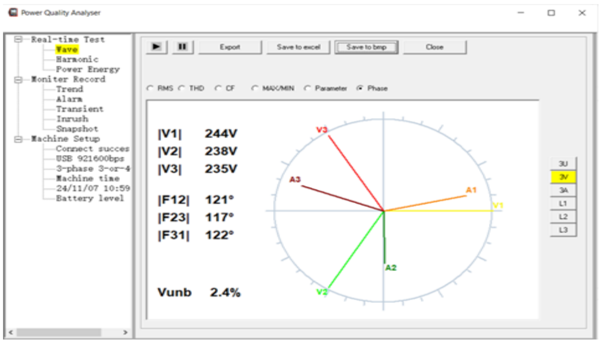
Figure 11 Performance of Synchronous Motor at Unbalance Condition (over) for Unity p.f

Machine setup information
Machine ti 24/11/7 10:58:7
Reacitve v Without harmonic
Electrial cc 3-phase 4-wire

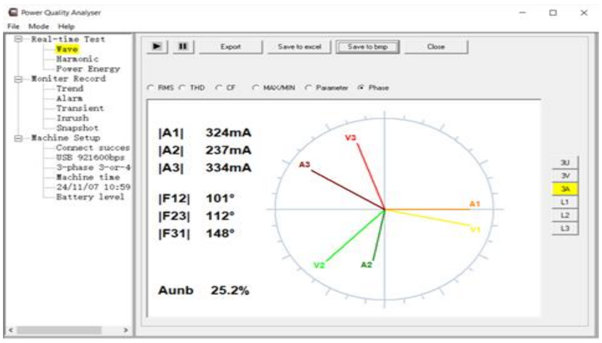
	L1	L2	L3	?	avg
W	74.82	46.56	60.59	182	
VAR	Capacitive	Capacitive	Capacitive	Capacitive-97.20	
VA	79.06	57.38	78.42	214.9	
Consume energy					
Wh	0	0	0	0	
VARh	Inductive0	Inductive0	Inductive0	Inductive0.000	
	Capacitive	Capacitive	Capacitive	Capacitive0.000	
VAh	0	0	0	0	
Generate energy					
Wh	0	0	0	0	
VARh	Inductive0	Inductive0	Inductive0	Inductive0.000	
	Capacitive	Capacitive	Capacitive	Capacitive0.000	
VAh	0	0	0	0	
PF	0.946	0.811	0.772		0.843
cosf	0.971	0.838	0.781		0.863
tanf	-0.244	-0.653	-0.799		-0.565
fVA	-13.6	-33	-38.6		

Energy calculate start time:
#########
Energy calculate stop time:
#########

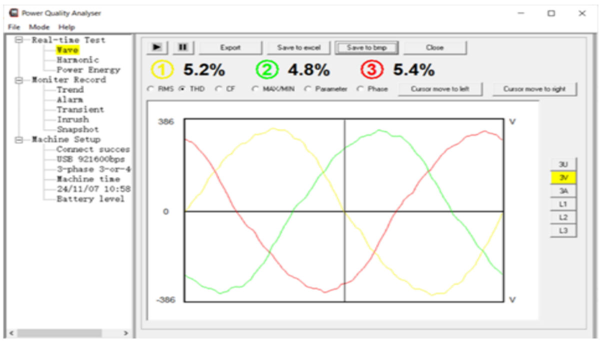
Table 9 Input Power and power Factor at Unbalance Condition for Leading p.f



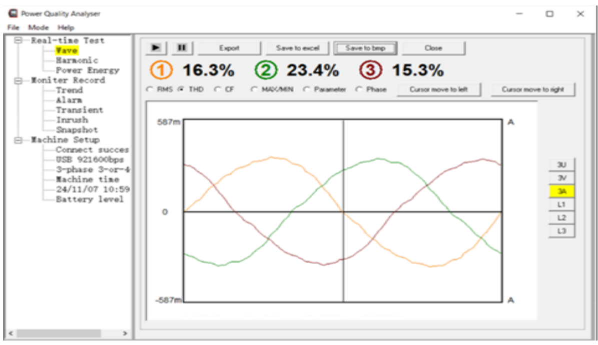
(a) Three phase voltage magnitude and phases



(b) Three phase current magnitude and phases



(c) Three phase voltage THD



(d) Three phase current THD

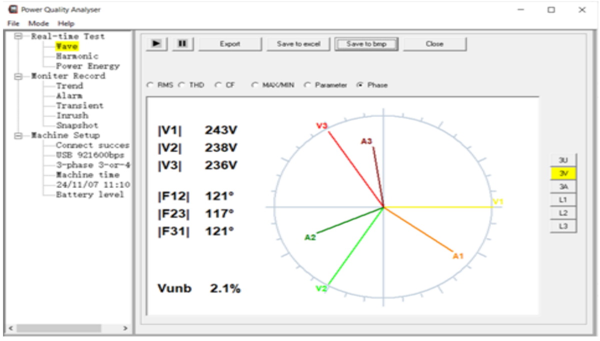
$I_{exc}(A)$	$I_L(A)$	$V_L(V)$	$P_{out}(w)$	$T(N.m)$	$Eff.$	Speed(rpm)
0.37	0.32	247	87.8	0.2794	0.482	3000

(E) Result for Leading p.f

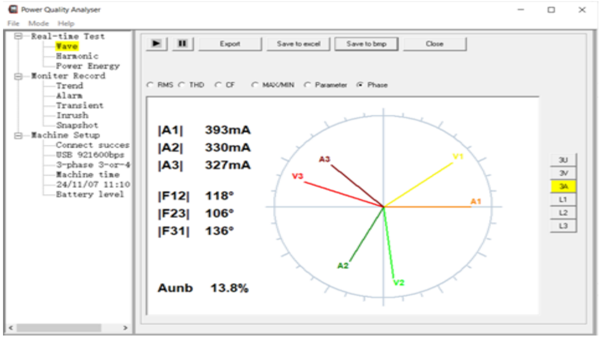
Figure 12 Performance of Synchronous Motor at Unbalance Condition (over) for Leading p.f

Machine setup information					
Machine ti 24/11/7 11:8:19					
Reacitve v Without harmonic					
Electrial cc 3-phase 4-wire					
	L1	L2	L3	?	avg
W	75.42	63.55	70.31	209.3	
VAR	inductive5	inductive4	inductive2	inductive132.6	
VA	96.63	79.05	76.71	252.4	
Consume energy					
Wh	0	0	0	0	
VARh	Inductive0	Inductive0	Inductive0	Inductive0.000	
	Capacitive	Capacitive	Capacitive	Capacitive0.000	
VAh	0	0	0	0	
Generate energy					
Wh	0	0	0	0	
VARh	Inductive0	Inductive0	Inductive0	Inductive0.000	
	Capacitive	Capacitive	Capacitive	Capacitive0.000	
VAh	0	0	0	0	
PF	0.78	0.803	0.916		0.833
cosf	0.793	0.82	0.922		0.845
tanf	0.773	0.704	0.419		0.632
fVA	37.5	34.9	22.7		
Energy calculate start time:					
#########					
Energy calculate stop time:					
#########					

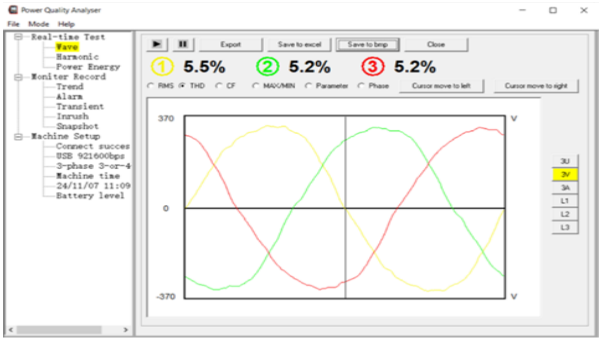
Table 10 Input Power and power Factor at Unbalance Condition (over) for Load Lagging p.f



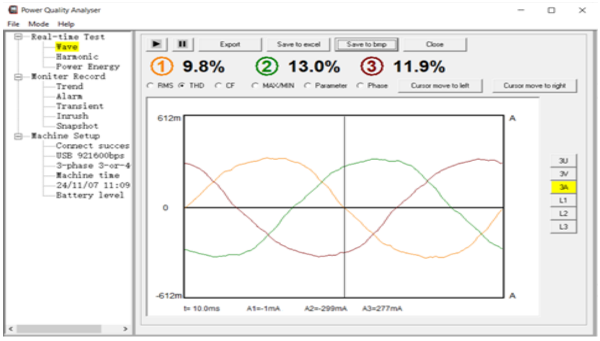
(a) Three phase voltage magnitude and phases



(b) Three phase current magnitude and phases



(c) Three phase voltage THD



(d) Three phase current THD

$I_{exc}(A)$	$I_L(A)$	$V_L(V)$	$P_{out}(w)$	$T(N.m)$	$Eff.$	Speed(rpm)
0.2	0.32	247	87.8	0.2794	0.42	3000

(E) Result for Lagging p.f

Figure 13 Performance of Synchronous Motor at Unbalance Condition (over) for Load Lagging p.f

DISCUSS OF THE RESULTS

the motor was tested by applying a balanced voltage with a load of 87.8 wat for three cases: unity, leading and lagging. then the motor was tested by applying an unbalanced voltage suddenly in two states: under voltage in magnitude and over voltage in magnitude with remaining the same load and the same excitation current for each case. these results were obtained

	Balance	Over	Under
$I_{sa}(A)$	0.225	0.322	0.242
$I_{sb}(A)$	0.276	0.241	0.450
$I_{sc}(A)$	0.306	0.284	0.335
$I_{sa}\ THD$	18.8%	13.8%	51.7%
$I_{sb}\ THD$	10.4%	19.4%	26.2%
$I_{sc}\ THD$	10.7%	14.8%	36%
$P_{in}(w)$	185.6	195	194.1
$Q(var)$	4.411	16.30	-41.69
$P.f$	0.98	0.965	0.864

Table 11 Result for Unity Power factor

	Balance	Over	Under
$I_{sa}(A)$	0.263	0.324	0.350
$I_{sb}(A)$	0.317	0.238	0.517
$I_{sc}(A)$	0.321	0.334	0.323
$I_{sa}\ THD$	19.0%	16.3%	36%
$I_{sb}\ THD$	19.0%	23.4%	23.8%
$I_{sc}\ THD$	15.7%	15.3%	40.2%
$P_{in}(w)$	175.6	182	184.1
$Q(var)$	-106	-97.2	-142.2
$P.f$	0.841	0.841	0.715

Table 12 Result for Leading Power Factor

	Balance	Over	Under
$I_{sa}(A)$	0.320	0.395	0.242
$I_{sb}(A)$	0.359	0.332	0.437
$I_{sc}(A)$	0.377	0.324	0.432
$I_{sa}\ THD$	20.0%	9.8%	45.5%
$I_{sb}\ THD$	14.8%	13.0%	24.5%
$I_{sc}THD$	11.9%	11.9%	24.0%
$P_{in}(w)$	204.3	209.3	208.2
$Q(var)$	124.6	132.6	83.75
$P.f$	0.833	0.833	0.84

Table 13 Result for Lagging Power Factor

we note from the results above when there is an unbalance in voltage the motor draws a higher current than when the voltage is balance, which leads to increased copper losses. each of the three phases will draw unequal currents. which will result in an uneven distribution of the load over the motor windings. Real input power (active power) is impacted by changes in reactive power caused by unbalanced voltage, where we notice reduce the power factor and increase input power which leads to reduced efficiency.

The motor's production of reactive power increases when the power factor is at unity and an unbalanced voltage (under) is applied. Consequently, the motor runs in the lead power factor. in the case of leading power factor and applying unbalance voltage (under) we also notice an increase in the production of reactive power. while, when lagging occurs and an unbalanced voltage (under) is applied, the motor import for reactive power will decrease.

we note from the results above an increase in harmonic when the voltage is under the rated. Increasing these harmonics means increasing the iron losses, which affects the efficiency of the motor because the motor converts electrical energy into thermal energy instead of mechanical energy.

there was no device available in the laboratory to measure torque, and this makes the results depend on ideal mathematical assumptions. Mathematical calculation of torque is limited because it does not take into account the dynamic factors that may occur in reality. where the torque was calculated using an equation based on the theoretical data such as mechanical power and the angular velocity. So, it has not notice change in the torque value

CONCLUSION

synchronous motor is an electrical apparatus that is susceptible to variations in the voltage of the supply When the three-phase voltage values mismatch in value or angle, an imbalanced voltage occurs, it causes an imbalanced current to emerge in the coils. This could result in unequal overheating of the windings and stress on them. Sensors that measure temperature can be used to keep an eye on this overheating or by manually monitoring the motor casing's temperature, which can lead to mechanical failures or damage to the insulation inside the motor casing. Unwanted harmonic current is produced by unbalanced voltages. These harmonics decrease efficiency and cause the motor to lose more losses. Additionally, affect the rotor and raise the heat produced within it. it also generates high currents in the zero phase in practical system using neutral points, this may lead to additional problems in distribution or protection networks. In order to maintain the same power level, the synchronous motor must draw more current when the voltage falls below the rated amount. Thus, the THD value rises as the harmonic currents are amplified. also, Low voltage distorts the electromagnetic wave by affecting the magnetic flux inside the motor. consequently, more undesired harmonics are produced by this distortion.

Depending on the power factor unbalance voltages have an impact on the synchronous motor. These impacts show up as adjustments to electrical current, efficiency, power factor and harmonic. A voltage imbalance has no direct effect on a synchronous motor's speed because it is dependent on the network's electrical frequency and the number of motor poles rather than voltage. The synchronous speed will not change as long as the frequency never changes. but A voltage imbalance can cause issues that impact the motor's operation even when the synchronous speed remains constant. For instance, more vibration. where the motor's windings experience unbalanced currents due to an imbalanced voltage, this causes the magnetic field to have a negative component. These parts generate counterforce, which results in mechanical vibrations and disruptions.

REFERENCES

[1] Neidhoefer, G. J. "Evolution of the synchronous machine." REVUE ROUMAINE DES SCIENCES TECHNIQUES SERIE ELECTROTECHNIQUE ET ENERGETIQUE 37 (1992): 334-334..

[2] Alolah, A. I. "Balanced operation of three phase synchronous motors connected to a single phase supply." IEMDC 2001. IEEE International Electric Machines and Drives Conference (Cat. No. 01EX485). IEEE, 2001.

[3] Sen, Paresh Chandra. Principles of Electric Machines and Power Electronics, International Adaptation. John Wiley & Sons, 2021.

[4] "ELECTRICA MACHINE with MATLA." [Online]. Available: www.engbookspdf.com

[5] Adekitan, Aderibigbe Israel. "A new definition of voltage unbalance using supply phase shift." Journal of Control, Automation and Electrical Systems 31.3 (2020): 718-725.

[6] Oluseyi, P. O., et al. "Assessment of the influence of voltage unbalance on three-phase operation of power system." Nigerian Journal of Technology 40.5 (2021): 901-912.

[7] Ferreira, F. J. T. E., A. De Almeida, and M. Cistelecan. "Voltage unbalance impact on the performance of line-start permanent-magnet synchronous motors." Proceedings of the 6th International Conference EEMODS, Nantes, France. 2009.

[8] Kebir, Ahmed Amine, Mouloud Ayad, and Saoudi Kamel. "Effects of harmonics and voltage unbalance on the behavior of a five-phase permanent magnet synchronous machine." Archives of Electrical Engineering (2022): 471-488.

[9] Qadir, Brzo Aziz. "Investigate the performance characteristics of three phase synchronous machine." Measurement: Sensors 29 (2023): 100811.

[10] Mathworks, "SimPowerSystems:Model and Simulate Electrical Power System." http://www.mathworks.com.au/products/simpower. 2021.

[11] Lipo, Thomas A. Analysis of synchronous machines. CRC press, 2017.

[12] Arranz-Gimon, Angel, et al. "A review of total harmonic distortion factors for the measurement of harmonic and interharmonic pollution in modern power systems." Energies 14.20 (2021): 6467.

[13] Kocatepe, Celal, et al. "Harmonic effects of power system loads: An experimental study." Power Quality Issues. IntechOpen, 2013.